

STATE OF CALIFORNIA  
DEPARTMENT OF TRANSPORTATION  
DIVISION OF ENGINEERING SERVICES  
OFFICE OF TRANSPORTATION LABORATORY

DEVELOP GUIDELINES FOR BENDING  
AND SPLICING REBAR

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84-09

PO-A8

1. REPORT NO. FHWA/CA/TI-84/09	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE  DEVELOP GUIDELINES FOR BENDING AND SPlicing REBAR		5. REPORT DATE June 1984	
		6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S)  Frank O. Reed		8. PERFORMING ORGANIZATION REPORT NO.  57325-636962	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Transportation Laboratory California Department of Transportation Sacramento, California 95819		10. WORK UNIT NO.	
		11. CONTRACT OR GRANT NO. F81TL34	
12. SPONSORING AGENCY NAME AND ADDRESS  California Department of Transportation Sacramento, California 95807		13. TYPE OF REPORT & PERIOD COVERED  Final	
		14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES  This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.			
16. ABSTRACT <p>The properties of rebars were measured after they had been bent and straightened both hot and cold. Various direct and indirect bar splices were welded and tested. Bars with thermocouples were set in concrete with 1-1/2" to 6" sticking out. Bars were welded onto these ends while the temperatures of the embedded bar were recorded at depths of 1/4", 1/2", 1", 1-1/2", 2", 2-1/2", 4" and 6". The concrete was sectioned to measure the depth of any heat cracks noted.</p> <p>Test results indicate that:</p> <ol style="list-style-type: none"> <li>1) Bars should not be bent and straightened cold more than once.</li> <li>2) No. 8 and larger bars should not be cold bent and cold straightened.</li> <li>3) Hot bending and straightening should be done between 1400° and 1500°.</li> <li>4) Direct splices on embedded bars should be at least 2" from the concrete.</li> <li>5) Indirect splices may be made with the lap bar touching the concrete.</li> <li>6) Bars of any size may be spliced successfully by using 100% butt welds or threaded, filler metal, and swaged sleeve couplers. No. 8 and smaller bars may also be spliced successfully by using a 75% butt weld backed with a flare weld lap splice or a flare weld double lap splice.</li> </ol>			
17. KEY WORDS Steel, reinforcement, concrete bending, splicing, welding, preheat, temperature.		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. SECURITY CLASSIF. (OF THIS REPORT)  Unclassified	20. SECURITY CLASSIF. (OF THIS PAGE)  Unclassified	21. NO. OF PAGES	22. PRICE



# CONVERSION FACTORS

## English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in <sup>2</sup> )	6.432 x 10 <sup>-4</sup>	square metres (m <sup>2</sup> )
	square feet (ft <sup>2</sup> )	.09290	square metres (m <sup>2</sup> )
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft <sup>3</sup> )	.02832	cubic metres (m <sup>3</sup> )
	cubic yards (yd <sup>3</sup> )	.7646	cubic metres (m <sup>3</sup> )
Volume/Time			
(Flow)	cubic feet per second (ft <sup>3</sup> /s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s <sup>2</sup> )	.3048	metres per second squared (m/s <sup>2</sup> )
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s <sup>2</sup> )
Weight	pounds per cubic (lb/ft <sup>3</sup> )	16.02	kilograms per cubic metre (kg/m <sup>3</sup> )
Density			
Force	pounds (lbs)	4.448	newtons (N)
	kips (1000 lbs)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds (ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi √in)	1.0988	mega pascals √metre (MPa √m)
	pounds per square inch square root inch (psi √in)	1.0988	kilo pascals √metre (KPa √m)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{t_F - 32}{1.8} = t_C$	degrees celsius (°C)



## ACKNOWLEDGEMENTS

The following individuals are recognized with appreciation for their work on this project.

Testing and Research	Steve MacLennan Andy Gust
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Testing	Walt Richards Ron Rehwald
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Welding	Jack Trimble Art Berkhimer
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Instrumentation	Richard Johnson Bob Caudle Bill Ng
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Drafting	James Donaldson
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Word Processing	Darla Bailey
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## 1. INTRODUCTION

### Problem

There are many instances during construction of reinforced concrete structures where partially embedded reinforcing steel bars (rebars) are in the way of a necessary operation. The question that comes up is: Can the bars be bent out of the way and later be restraightened? If the inspector allows the bars to be bent and straightened, what is the minimum bending radius that should be allowed? And, should the bars be heated while bending? -- straightening? And, what temperature or color should the bar be heated to?

If bars are broken or need to be extended, how should they be spliced? Is butt welding the best method, or would welding with a splice bar for the size bar in question be better? Or, would a mechanical coupler be the best method? Are there approved methods for splicing reinforcing steel?

There are, of course, approved methods for bending and splicing reinforcing steel -- ASTM(5), ACI(3), CRSI(2), AWS(1), but these specifications are designed for new construction and do not cover all situations encountered in the field. For example, the minimum radii for bends and bend tests in the above specifications are intended for the bar to be bent once only on a machine with formers (pins) that freely turn and with sufficient power to make the bend with one continuous uniform application of force. Field bends are usually made by an ironworker using a hickey bar.

Similarly, if it is necessary to weld reinforcing bars in the field, some of the questions that come up are: What type and size electrode should be used and what kind of joint is best for the situation? If the existing bar is Grade 40 and Grade 60 is specified for the new construction, what is the procedure for splicing them?

Usually, when these types of questions arise, the need for a solution is immediate. However, the average field inspector, designer, structural engineer, or resident engineer does not have a straightforward simple set of guidelines to follow that will advise him on an appropriate course of action.

### Objective

The aim of this project is to develop a brief understandable document that will provide useful guidance to design, construction and maintenance personnel who must select and/or inspect rebar bending and splicing procedures which are appropriate for transportation applications.

## 2. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

A. When the carbon equivalent is unknown, the best and safest way to bend and straighten reinforcing steel is by thoroughly heating it to 1400-1500°F (using tempil sticks for accurate temperature control) and bending around the largest radius practicable. See Table A, Appendix A for minimum bend radii. Bending and straightening temperatures outside this range should be avoided.

B. After a reinforcing bar has been bent and straightened once, it should not be subjected to further bending.

C. No. 8 and larger reinforcing bars should not be cold bent and cold straightened.

D. Single lap welded splices should not be used with normal concrete cover (2")(2) because of the tendency of this detail to rotate and cause spalling under the application of axial tension.

E. Where butt welds are made on bars up to and including No. 8 at a minimum distance of 2 inches from the concrete surface and there is at least 2-1/2 inches of concrete cover, cracking should not extend greater than 2 inches into the concrete.

Similarly, when a 75 percent butt and flare groove lap splice combination is made on No. 5 bars at the minimum distance from the concrete surface permitted by the lap bar, cracking should not extend more than 1/2 inch into the concrete.

F. When embedded rebars are welded near the concrete surface, cracking is caused by the more rapid thermal expansion of the steel and thermal stresses and strains set up in the concrete. This action is similar to that produced by corrosion of reinforcing steel in bridge deck concrete.

G. Although reinforcing bars may be successfully butt welded without preheating and controlled cooling, better results are obtained with controlled preheat and controlled cooling.

H. Size 8 and smaller rebars may be successfully spliced with a double lap splice or a 75 percent butt weld flare groove lap splice combination.

I. If possible, the rebar should be bent around a freely turning roller.

#### IMPLEMENTATION

The guidelines in Appendix A will be made available to designers, construction personnel, and maintenance personnel.

### 3. DESCRIPTION OF TESTS

#### 3.1 Reinforcing Steel Used

It was decided early in the program that it would be advantageous to obtain one heat for each size rebar tested.

Grade 60 reinforcing bars with relatively high carbon equivalents were chosen to represent the "worst" case.

Two sizes of bars, No. 5 and No. 8, were selected to represent the range of smaller size bars, and also, the range of bars that might be successfully bent and straightened.

Sufficient data exist for recommending splicing methods for the larger bars.

#### 3.2 Bend Tests

Bend tests were made on No. 5 and No. 8 ASTM A615 Grade 60 reinforcing steel. Each size was from a single heat of steel and of a relatively high carbon equivalent. The chemistries of each heat and the calculated carbon equivalents are presented below in Table 1.

TABLE 1

	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Sn	C.E.
#5	0.43	1.22	0.018	0.033	0.23	0.28	0.09	0.10	0.001	0.02	0.024	0.654
#8	0.44	1.27	0.049	0.033	0.24	0.28	0.11	0.16				0.680

C.E. Calculated From

$$\%C + \frac{\%Mn}{6} + \frac{\%Cu}{40} + \frac{\%Ni}{20} + \frac{\%Cr}{10} - \frac{\%Mo}{50} - \frac{\%V}{10}$$

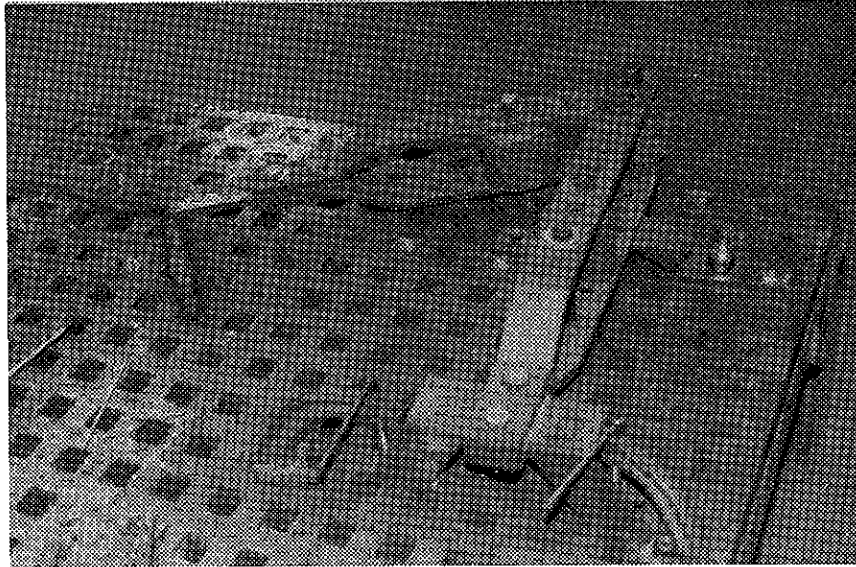
The formula used for calculating the C.E. is from AWS, D1.4-79.

Various bend diameters, preheat temperatures and cooling rate control were investigated. All bends were made to approximately 90° with a bend fixture (Figure 1). The bend fixture was equipped with roller formers of 1, 2, 3, 4, 5, and 8-inch diameters and freely turning rollers as required by ACI and ASTM.

After bending, the bars were straightened by placing them in a vise and progressively moving along the bend with a hickey bar until sufficiently straight for tensile testing.

### 3.3 Tensile Tests

Tensile tests were made in a Baldwin Universal testing machine, 440 kip capacity. The loading rate was approximately 30 kips per minute.



Bend Fixture

Figure 1

An 8-inch gage length was used for elongation measurements. The gage marks were put on the 40-inch lengths of bars before initial bending. Percent elongation, yield and ultimate strengths were recorded, if possible\*, for comparison with control tests run on bars not bent and straightened.

A set of reduced tensile test specimens was taken from the bent and straightened sections of No. 5 bars that were:

- ° Bent and straightened cold.
- ° Bent at 1400-1500°F and straightened at 1400-1500°F. One set was prepared from bars not bent and straightened.

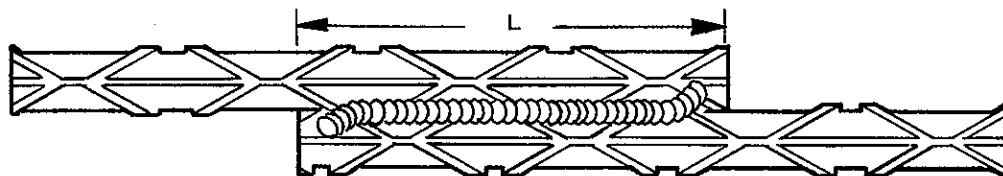
All bars that were bent for the reduced tensile tests were bent around a 3-inch diameter pin.

The object of this test was to ensure testing the bent and straightened portion of the bar. One researcher(11) pointed out that a bar that has been bent, straightened, and subsequently tensile tested will fail in an area outside the bent and straightened area. And thus, subsequent tests would be testing the original bar and not the bent section.

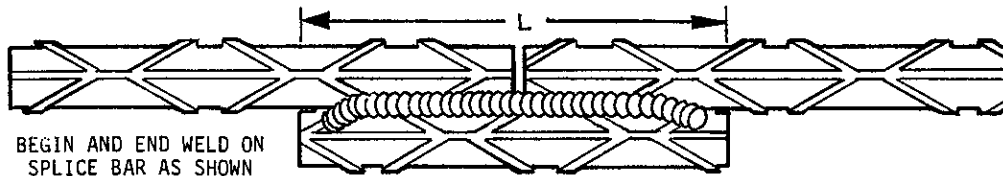
### 3.4 Weld Tests

The types of weld splices tested are depicted in Figure 2.

\*Percent elongation was disregarded when bar failed outside gage marks.



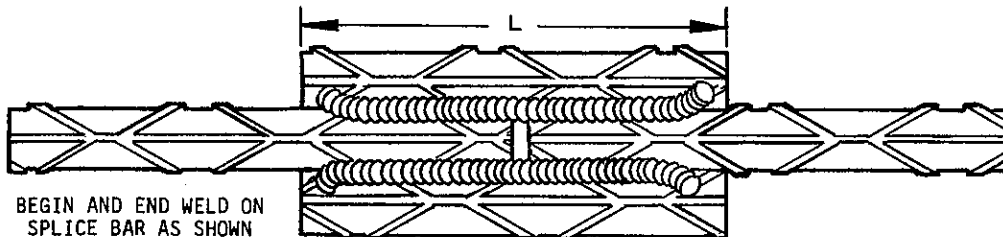
**Type 1**



**Type 2  
Detail 1**

SINGLE LAP SPLICE  
WITH FLARE V GROOVE WELD

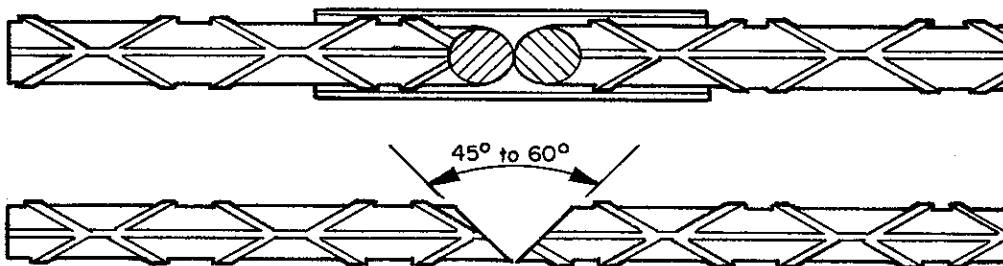
- a. WELD ONE SIDE
- b. WELD BOTH SIDES



**Detail 2**

DOUBLE LAP SPLICE  
WITH FLARE V GROOVE WELD

- a. WELD ONE SIDE
- b. WELD BOTH SIDES

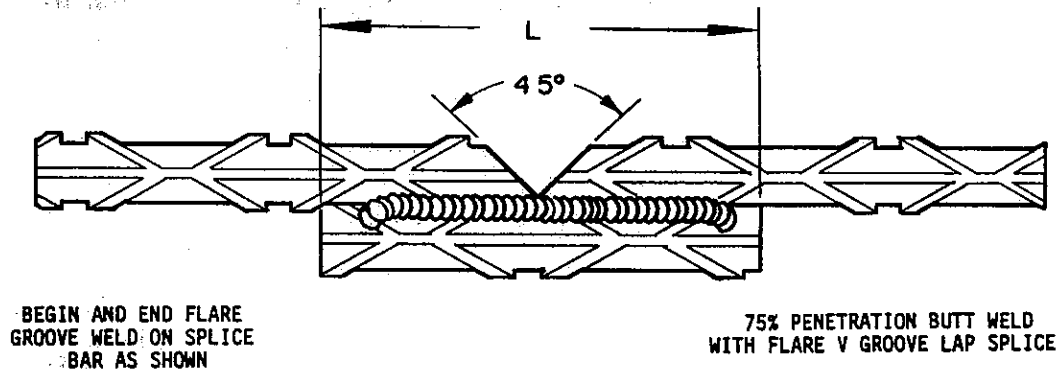


**Detail 3**

100% PENETRATION BUTT WELD

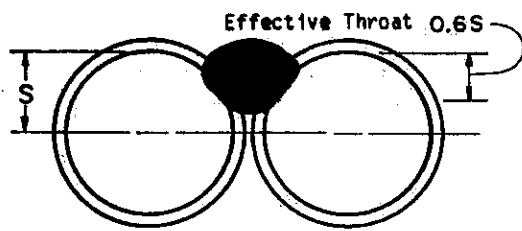
- a. WITH SPLIT PIPE BACKING
- b. NO BACK UP

**Figure 2**

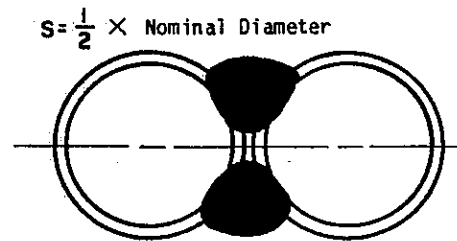


## Detail 4

A.W.S. Value For Flare V Groove Welds



1. FLARE V GROOVE  
WELDED ONE SIDE



2. FLARE V GROOVE  
WELDED BOTH SIDES

Dimensions for Weld Details			
Bar Size	$\ell^*$	$\ell'$	L
#4	1.31	3	4
#5	1.64	4	5
#6	1.96	5	6
#7	2.29	6	7
#8	2.62	7	8

$\ell$  = Minimum calculated weld length (inches) for bars welded on one side.

$\ell'$  = Recommended weld length (inches) for all cases.

L = Recommended lap or splice length (inches).

\* Double  $\ell$  values for Detail 1 type 2.

Figure 2

All welds were made with E7018 or E9018 low hydrogen electrodes shielded metal arc process (SMAW). Various preheat and post temperature controls were used. Weld splices were tested in tension to determine the effectiveness of each type.

### 3.5 Bars Embedded in Concrete

No. 5 and No. 8 bars were embedded in 6"x10"x12" concrete blocks to a depth of 12 inches. Iron-constantan thermocouples were attached to the surfaces of the bars at various depths to measure the temperature of the bars while a weld splice was being made in close proximity to the concrete surface.

After the weld splice was made, the concrete block and rebar were sectioned at approximately 1/2 inch intervals to determine the extent and depth of cracking, if any.



## 4. DISCUSSION

### 4.1 Rebar Bending

#### 4.1.1 No. 5 Bars

One hundred and four bend tests on No. 5 bars at various bend diameters and temperature conditions are presented in Table 2.

An oxy-acetylene torch with a rosebud tip was used to heat the bars and temperature sticks were used to estimate temperature. A large enough area was heated to fully cover the bend zone when bending and when straightening.

Eight bars that were heated in the 1800°F range, bent around 4- and 5-inch formers and subsequently straightened at 1800°F, showed a decrease in ductility and ultimate strength. One bar of this set failed during straightening. Two of another set of 5 bars bent around a 4-inch former at 1800°F and straightened with a hickey bar at 1800°F failed during straightening. All of 10 bars bent at 1800°F around a 5-inch former fractured when attempting to straighten them cold.

The 1800°F temperature is above the upper transformation temperature for carbon steel (1667°F) and a brittle martensitic grain structure is a possibility at the surface of the bar. Consequently, this temperature should be avoided. It is also felt that judging the temperature from the color is not accurate enough because of variable lighting conditions. Temperature sticks should be used to ensure that undesirable temperature ranges are avoided.

# #5 Bending

Bars Tested	Pin Dia.	Bend Temp.	Straighten Temp.	Avg. % Elong.	Yld. Str. Avg. ksi	Ult. Str. Avg. ksi
7		Control		17	69.5	111.9
5	5	1200	1200	-	69.9	103.0
6	5	60	60	-	69.9	112.5
5	3	60	60	16	69.7	112.5
10	4	60	60	16	69.8	112.1
5	5	60	60	15	69.7	112.4
5	4	1800	1800	-	70.6	107.7
Two of 5 broke during straightening.						
5	4	60	60	-	69.7	110.4
Bars allowed to rest 30 days before straightening and testing.						
5	4	60	60	-	69.7	112.0
Bars allowed to rest 60 days before straightening and testing.						
3	4	1800	1800	10	68.4	106.6
5	5	1800	1800	10	70.2	105.5
One fractured during straightening.						
4	2	60	60	6	69.8	106.7
5	1	60	1400-1500	8.8	70.7	106.5
4	1	1400-1500	1400-1500	8.5	71.1	103.1
10	5	1800	60	All failed during straightening.		
5	5	60	600	All failed during straightening.		
5	1	60	1100-1200	All failed during bending.		
5	2	60	60	1-1/2 cycles All broke straightening second time.		
5	2	1400-1500	1400-1500	Bent and straightened 3 cycles. All failed when attempting to bend 4th time.		

TABLE 2

Another temperature that produced poor results was 600°F, which is in the blue brittle range (450°F-650°F). This was encountered early in the program when heating five bars that had been bent cold to 600°F for straightening. All five bars failed during straightening and the broken ends displayed the characteristic blue color of the blue brittle range. Five other bars cold bent around a 1-inch former and heated to 1100-1200°F for straightening also failed while straightening and exhibited the blue color. Apparently the bars were not heated long enough to bring the centers of the bars above the blue brittle range.

Five bars heated to 1200°F for bending around a 5-inch former and heated to 1200°F for straightening showed a slight increase in yield strength and an 8 percent decrease in ultimate strength.

Five, 10 and 5 bars cold bent around 3-, 4- and 5-inch formers, respectively, and cold straightened showed a slight increase in yield and ultimate strengths and a slight decrease in % elongation.

Two sets of five bars each were cold bent and cold straightened around a 4-inch former and allowed to strain age 60 days and 90 days. The yield and ultimate strengths of these two sets when tensile tested were not appreciably different from the control yield and ultimate strengths.

In order to determine if the tests on the full size bars were valid and represented true tests of the bent and straightened areas, a set of five each reduced tensiles were taken from the bent and straightened areas of:

- ° bars bent and straightened cold around a 3-inch diameter former.
- ° bars heated to 1400-1500°F and bent around a 3-inch former and subsequently heated back up to 1400-1500°F and straightened.
- ° control bars not bent.

The results are presented in Table 3.

	<u>Yield Str.</u> <u>ksi</u>	<u>Ultimate Str.</u> <u>ksi</u>	<u>% Elongation</u> <u>in 1 inch</u>
Control	71.0	117.1	23.8
Cold bent Cold straighten	72.6	117.6	23.0
1400°F-1500°F bend 1400°F-1500°F straighten	69.6	109.3	25.2
Required	60.0 min	90.0 min	9.0 min.

TABLE 3

It can be readily seen that the cold bending and cold straightening increased the yield and ultimate strengths slightly and reduced the % elongation slightly. The hot bending and hot straightening, however, reduced the yield and ultimate strengths and increased the % elongation. These results are consistent with the results obtained from

tests on the full-size bars and validates those tests. The reason for the higher yield and ultimate strengths for the reduced tensile controls is that the nominal area (which is based on weight-including the deformations) is used for the full-size tests.

In order to test smaller diameter bends, two sets of bars were bent around 1-inch and 2-inch formers. One set of four was bent cold around a 2-inch former and straightened cold successfully, but resulted in a drastic reduction in % elongation when tested. The average % elongation for this group was 6.0, which is below the 9.0 required by ASTM A615. The average yield was up slightly and the ultimate was down about 4-1/2 percent from the control. The second set was bent cold around a 1-inch former and straightened successfully at 1400-1500°F. Again, the average % elongation was reduced greatly to 8.8, which would be borderline in meeting the ASTM specification. The yield was up slightly for this group and the ultimate was reduced about 5 percent. Another set of five bars was bent at 1400-1500°F around a 1-inch former and successfully straightened at 1400-1500°F. The results were very similar to the previous set bent cold and straightened at 1400-1500°F with a greater reduction in the average ultimate strength (7.9%).

As a demonstration of the loss in ductility due to bending and straightening, a set of five bars was bent cold around a 2-inch former and successfully straightened cold. It was then attempted to rebend the bars cold around the 2-inch former. All five bars failed to make the second bend.

In order to test the effectiveness of the 1400-1500°F temperature for bending and straightening, a set of five bars was bent and straightened repetitively around a 2-inch former. The set was successfully bent and straightened three full cycles, but all bars failed on the fourth attempt at bending.

#### 4.1.2 No. 8 Bars

The results of bend tests on No. 8 bars are presented in Table 4.

No. of Bars Tested	Pin Dia. inches	Bend Temp. °F	Straighten Temp. °F	Avg. % Elong.	Yld. Str. Avg. ksi	Ult. Str. Avg. ksi
10		CONTROL		16.7	66.6	109.7
5	8	60	60	7.8	56.1	80.4
		(one of five failed during straightening)				
3	4	1400-1500	1400-1500	10.5	63.6	95.2
3	8	1400-1500	1400-1500	15.3	62.3	96.9

TABLE 4

The results in Table 4 further demonstrate the effects of temperature and bend diameter. It would appear that the No. 8 size is on the dividing line of bar sizes that can be successfully bent and straightened, either hot or cold. The No. 8 bar is very difficult to bend without special equipment and even more difficult to straighten. Bending and straightening this size bar cold can be dangerous because of the forces involved and the possibility of unexpected brittle fracture of the bar. One bar of a group of five cold bent around an 8-inch former failed suddenly

while cold straightening and the average yield strength, average ultimate strength and % elongation of the remaining four bars suffered drastic reductions.

The two groups of bars bent around 4- and 8-inch formers at 1400-1500°F, and straightened at that temperature again, demonstrate the effect of bend radius. The average % elongation for the bars bent at the 8-inch diameter former is much nearer the control than is the average % elongation for the bars bent around the 4-inch diameter former. The yield and ultimate strengths are reduced but are well within the required minimum values of 60 ksi and 90 ksi.

## 4.2 Rebar Splicing

### 4.2.1 No. 5 Welded Splices

Section 52-1.08B "Butt Welded Splices" of the 1981 California Standard Specifications states that all welded splices in reinforcing steel shall be full penetration butt welds. This specification was intended for larger size bars — No. 9 through 18.

Normally, the most economical method for splicing the smaller sizes is by lapping. This, however, is not always possible during construction where it is necessary to splice to a short broken end or where it is necessary to splice to bars exposed for widening a structure. The results of various welded splice details (see Figure 2) using No. 5 bars and various preheating and cooling parameters are presented in Table 5.

TABLE 5

TENSILE TESTS ON WELDED SPLICES  
NO. 5 REINFORCING STEEL

No. Bars	Detail*	Preheat Temp. °F	Control Cooling	Electrode	Avg. Yld. ksi	Avg. Ult. ksi	Remarks
2	1a Type 1.	600	Yes	E9018	-	78.4	Large Eccentricity
2	1b Type 1.	600	Yes	E9018	-	105.2	Large Eccentricity
2	2a	600	Yes	E9018	-	110.3	Failure in HAZ
2	2b	600	Yes	E9018	-	110.0	Failure in HAZ
2	3a	60	No	E7018	69.7	104.1	Failure in HAZ
2	3b	60	No	E7018	70.0	95.8	Weld Failure
5	4	60	No	E7018	70.9	111.9	Failure in HAZ
5	4	600	Yes	E9018	70.9	111.7	Failure in HAZ
7	CONTROL				69.5	112.4	

\*See Figure 2 for explanation of details

Although the results from detail 1b, Type 1. are good, there was considerable deflection during the tensile tests and this detail should be avoided unless there is considerable constraint — such as transverse reinforcing steel or concrete cover sufficient to prevent spalling. Detail 1a, Type 1. exhibited greater deflection and failed below 80 ksi, which is required by California Standard Specification for butt welds.

Details 2a and 2b, with a 600°F preheat and controlled cooling, met the required 80 ksi and there was no problem with deflection.

Detail 3 gave good results with and without a backup and with no preheat, no controlled cooling, and using an E7018 electrode.

Detail 4 gave good results under two very different sets of variables. In one set, no preheat, no control cooling and an E7018 electrode were the parameters. In the second set, a 600 preheat, controlled cooling and a E9018 electrode were the parameters. As can be seen in Table 5, there is almost no difference in the average yield and average ultimate strengths for these two sets. This is probably due to the fact that the flare groove weld in itself provides enough weld area if the electrode used is E9018. With the 75 percent penetration butt weld, there is more than enough weld area whether the electrode is E7018 or E9018.

#### 4.2.2 No. 8 Welded Splices

The results of tensile tests on various welded splice details on No. 8 reinforcing steel are presented in Table 6.

TABLE 6

TENSILE TESTS ON WELDED SPLICES  
NO. 8 REINFORCING STEEL

No. Bars	Weld Detail	Preheat Temp. °F	Control Cooling	Electrode	Avg. Yld. ksi	Avg. Ult. ksi	Remarks
5	1a Type 2.	No	No	E9018	-	57.7	Large Deflection
5	1a Type 2.	200	Yes	E9018	-	57.5	Large Deflection
5	1a Type 2.	400	Yes	E9018	-	62.4	Large Deflection
5	1a Type 2.	600	Yes	E9018	-	54.4	Large Deflection
3	2a	No	No	E9018	-	97.2	Failures in Weld & HAZ
3	2a	600	Yes	E9018	-	108.4	Failures in Welds & Bar
5	3	No	No	E9018	-	94.7	Failures in Welds & Bar
5	3	200	No	E9018	-	93.6	Failures in Welds & Bar
5	3	400	No	E9018	-	96.4	Failures in Welds & Bar
5	3	600	No	E9018	-	93.9	Failures in Welds & Bar
3	3	No	No	E9018	-	88.4	Failures Ini- tiated in HAZ
3	3	600	Yes	E9018	-	95.4	Failures Ini- tiated in HAZ
3	4	No	No	E9018	-	99.4	Failures Ini- tiated in HAZ
3	4	600	Yes	E9018	-	103.6	Failures in Bar, HAZ, and Butt Weld

The single lap splices on the No. 8 bars, as expected, acted the same as the tests on the No. 5 bars and deflected greatly and produced low ultimate strength results. This detail is not recommended.

Looking at the overall results in Table 6, it can be stated that weld details 2, 3, and 4 produce satisfactory results whether there is preheat and controlled cooling or whether there is no preheat and no control cooling. But, better results are obtained with the 600° preheat and controlled cooling.

#### 4.3 ASTM A706 Reinforcing Bars

##### 4.3.1 Bending

ASTM A706 specification, unlike the A615 specification, which has only a phosphorous limit, has maximum limits for carbon, manganese, phosphorous, sulfur and silicon. It also has a maximum carbon equivalent of 0.55 calculated from the equation listed previously from AWS.

$$C.E. = \%C + \frac{\%Mn}{6} + \frac{\%Cu}{40} + \frac{\%Ni}{20} + \frac{\%Cr}{10} - \frac{\%Mo}{50} - \frac{\%V}{10}$$

The A706 specification also has a more stringent bending specification. Tables from ASTM A615 and ASTM A706 are reproduced in Figure 3 for comparison. Thus, if it is known ahead of time that bars must be bent and straightened, A706, as a rule, is more easily and more successfully bent and straightened.

A706

TABLE 3 Bend Test Requirements

Bar Designation No.	Diameter of Pin for 180 deg Bend Tests	
3,4, and 5	3d <sup>A</sup>	
6,7, and 8	4d <sup>A</sup>	
9,10, and 11	6d <sup>A</sup>	
14 and 18	8d <sup>A</sup>	

A<sub>d</sub>=nominal diameter of specimen.

A615

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for* Bend Tests	
	d=nominal diameter of specimen	
	Grade 40	Grade 60
3,4,5	4d	4d
6	5d	5d
7,8	5d	6d
9,10,11	5d	8d

\*Test bends 180° unless noted otherwise.

Figure 3

#### 4.3.2 Splicing

As pointed out in the previous section, the chemistry and carbon equivalent requirements for A706 are much more stringent than the requirements for A615. These requirements are designed to provide a bar that is more bendable and more easily welded. AWS requires only a 200°F preheat for welding the largest size bars when the carbon equivalent is 0.55 or less. A706 limits the C.E. to a maximum of 0.55. Where extensive welding is anticipated, especially in important elements such as a seismic resisting frame, A706 is recommended(2)

#### 4.4 Mechanical Couplers

Two types of mechanical couplers are approved for use in the January 1981 edition of the Caltrans Standard Specifications. These are the threaded sleeve type and the sleeve filler metal type. The mechanical couplers must provide the same minimum ultimate required of the full penetration butt welds and, in addition, must pass slip requirements. The slip requirements are a maximum of 0.010 inch and 0.030 inch for No. 14 and smaller and for No. 18, respectively, after loading to 30 ksi and relaxing to 3 ksi.

A sleeve swaged type mechanical coupler has been approved since the 1981 Standard Specifications. This type must meet the same requirements as the other two mechanical couplers.

One disadvantage of the mechanical couplers is maintaining concrete coverage over the sleeve which has a larger diameter. Another, is the specialized equipment needed.

#### 4.5 Bars Embedded in Concrete

Two bar sizes — No. 5 and No. 8 were instrumented with iron-constantan thermocouples along their surfaces and embedded in standard bridge mix concrete. The concrete blocks were 6x12 inches in cross-section and 12 inches in depth. (See Figure 4 for thermocouple arrangement.) The concrete blocks were allowed to cure in a moist cure room for 28 days and then removed. Concrete strength at 28 days was approximately 5000 psi. The blocks were stored in the test lab for several weeks before the weld splices were made on the rebar which extended approximately four inches out of the concrete.

A butt splice was made on the No. 8 bar approximately two inches from the surface of the concrete (Figure 5). While the butt splice was being made, surface temperature was recorded at seven locations along the bar at one minute intervals. A time temperature plot for each location is presented in Figure 6.

A few days after the weld was made, the block and rebar were sectioned with a diamond saw at approximately 1/2 inch intervals in order to determine the depth of cracking, if any. In Figure 7, successive slices are shown. Cracking can be seen (cracks marked with grease pencil) in slices 1 through 3, which represents approximately 1-7/8 inches into the concrete. Slice 4 is free of any cracking. The cracking, as could be expected, occurred in the direction of least concrete restraint.

It could be assumed from this that No. 8 bar could be butt-welded within two inches of the concrete and cracking would be limited to a depth of two inches providing similar cover exists.

# LOCATION OF THERMOCOUPLES ON REBAR EMBEDDED IN CONCRETE BLOCK

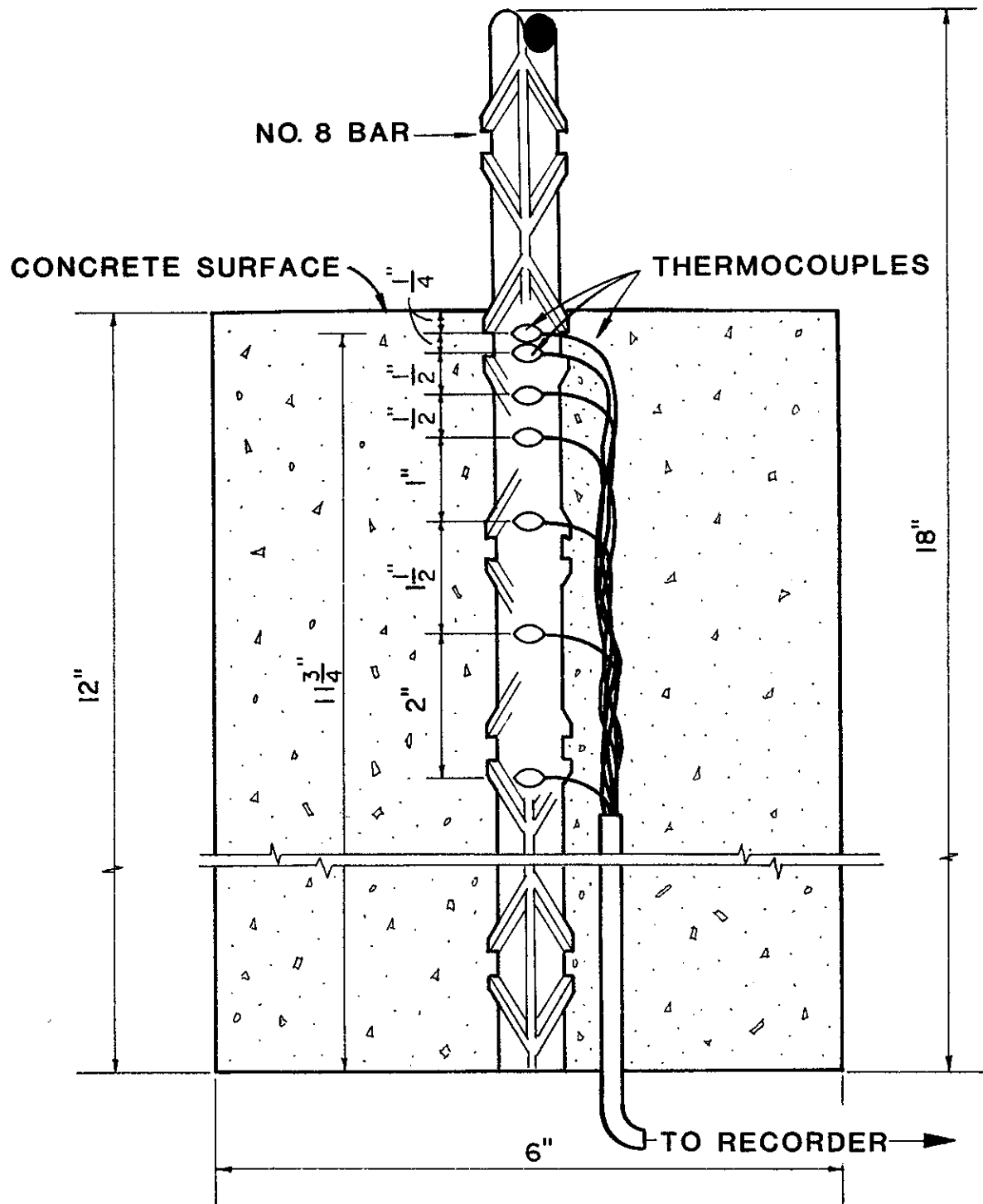
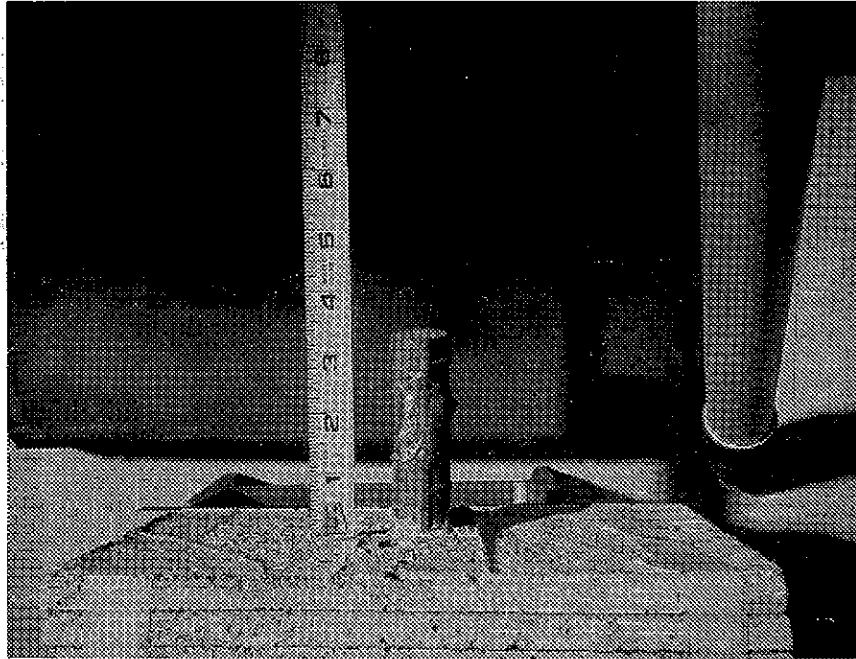


Figure 4



Butt Splice on No. 8 Bar  
Two Inches from Concrete Surface

Figure 5

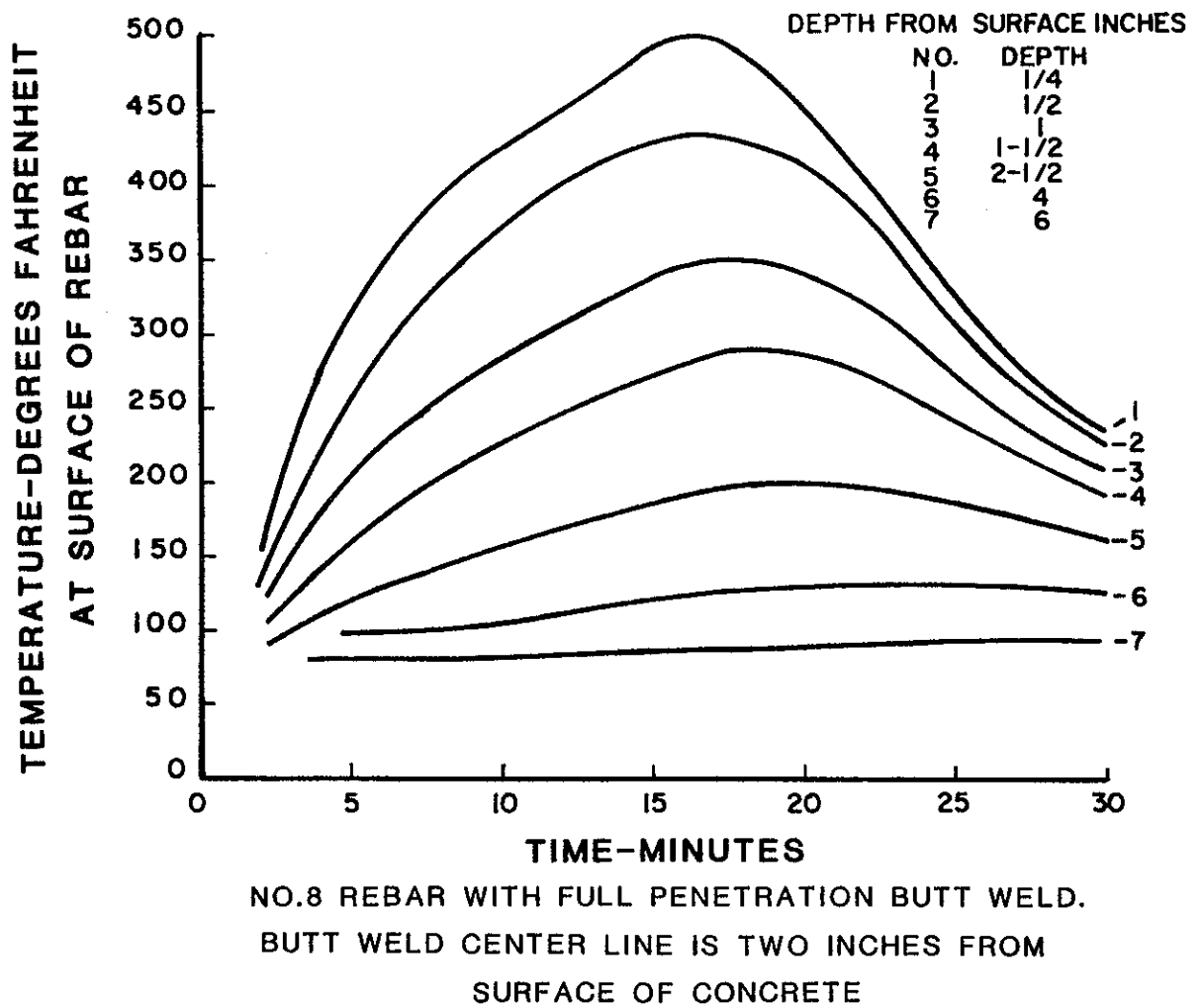
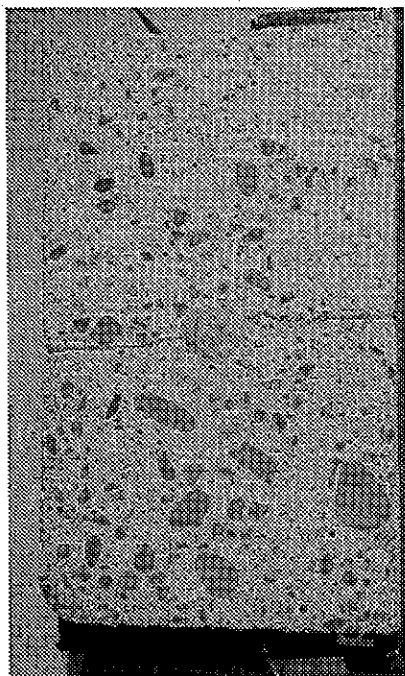
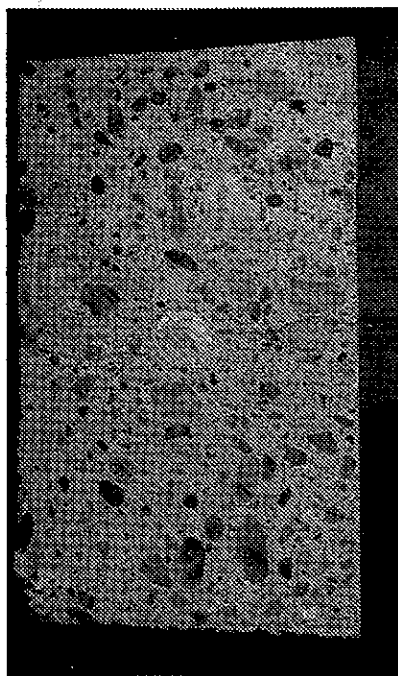


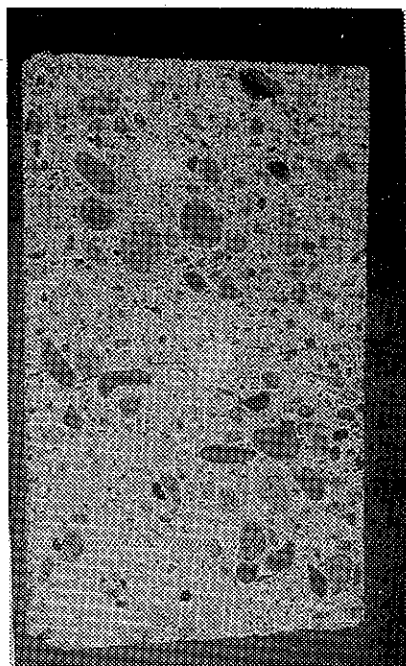
Figure 6



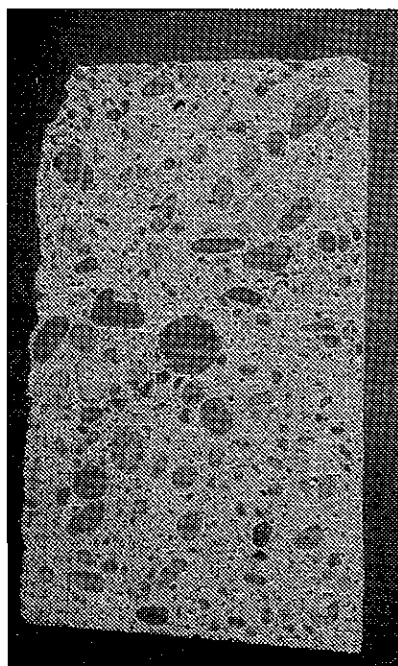
1



2



3



4

Successive slices through concrete block and No. 8 Bar which was butt welded 2 inches from concrete surface. Cracking occurred through three 1/2 inch slices.

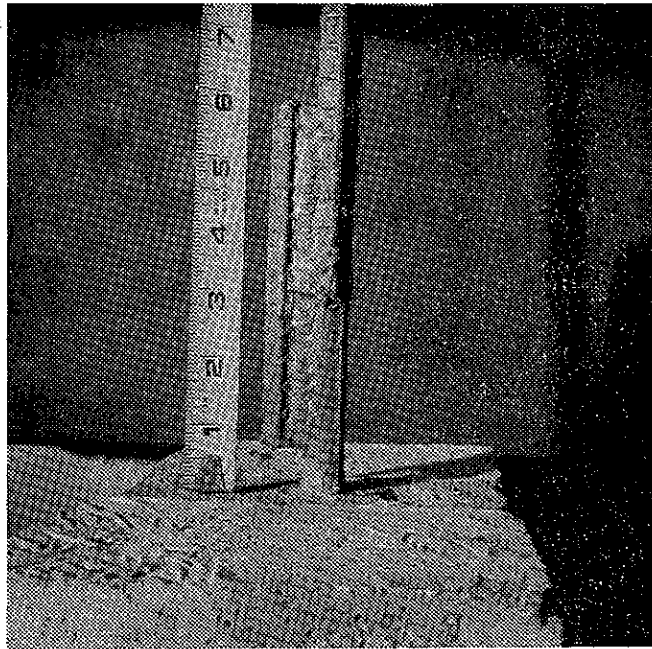
Figure 7

Looking at the time temperature plots in Figure 6, it can be seen that the bar surface temperature drops off rapidly from 500°F at 1/4-inch depth to 350°F at 1-inch depth. At 4-inch depth, the temperature only gets up to 130°F.

The No. 5 rebar was spliced with a flare groove weld and 75 percent butt weld combination (see Figure 8). The 75 percent butt weld was approximately three inches from the concrete and the flare groove weld to splice bar started at less than one inch from the concrete.

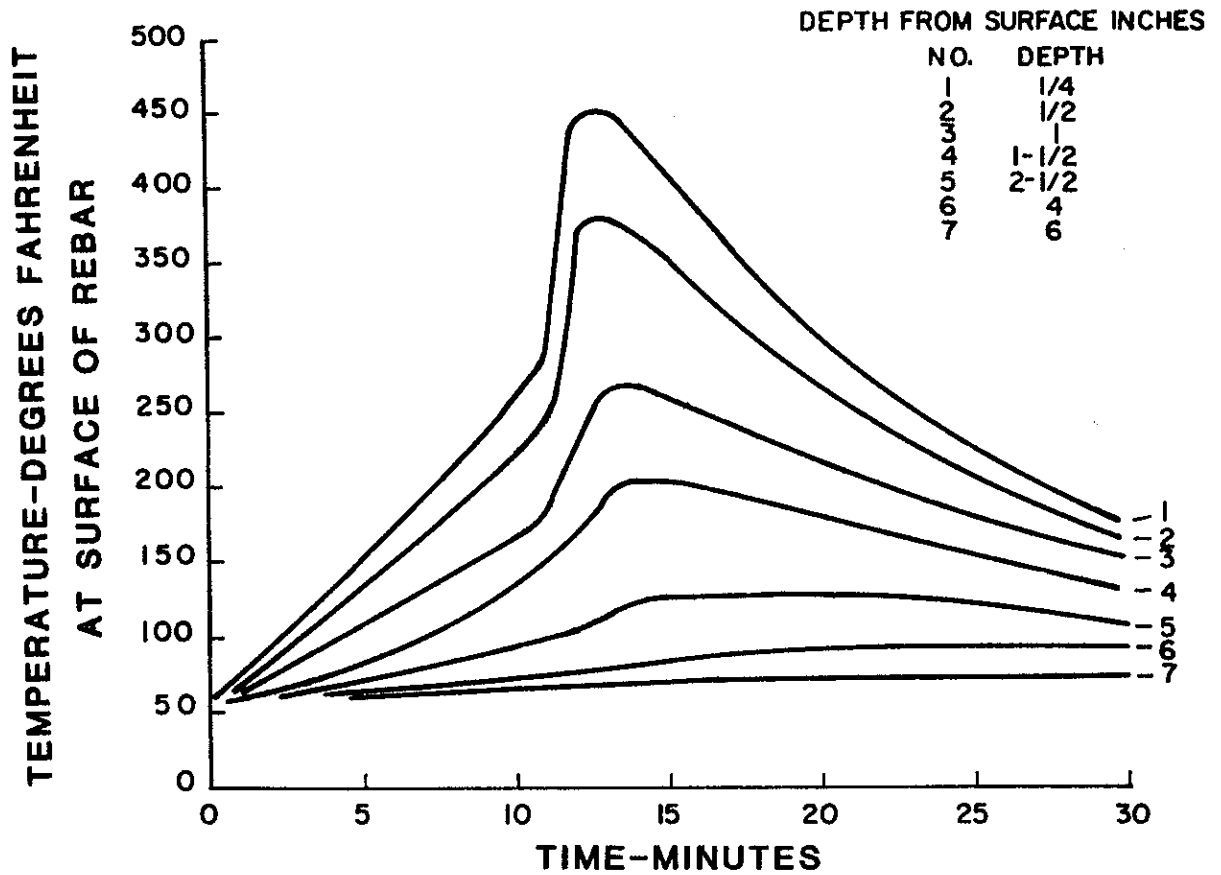
When slicing the block and bar, the first 1/2-inch slice broke up during cutting, but no crack was visible in the block surface after the first slice was removed.

Time temperature plots for each point on the bar that is instrumented with a thermocouple are presented in Figure 9. Looking at this plot, the highest temperature reached at the 1/4-inch depth is 450°F and the temperature at 4-inch depth reaches only 90°F. From this, it is concluded that this detail can be used and cracking will be minimal providing there is similar cover.



No. 5 Rebar — Embedded in Concrete and Spliced with  
75 Percent Butt Weld and Flare Groove Splice Bar

Figure 8



NO.5 REBAR WITH 75% BUTT WELD AND FLARE GROOVE LAP SPLICE  
BUTT WELD AND BEGINNING OF FLARE GROOVE WELD ARE 3 INCHES  
AND 3/4 INCH FROM SURFACE OF CONCRETE RESPECTIVELY.

Figure 9



## 5. REFERENCES

1. American Welding Society, "Structural Welding Code, Reinforcing Steel," AWS D1.4, 1979.
2. Concrete Reinforcing Steel Institute, "Manual of Standard Practice," MSP-1, 1980.
3. American Concrete Institute, "Building Code Requirements for Reinforced Concrete," ACI 318, 1977.
4. Concrete Reinforcing Steel Institute, "Reinforcement Anchorages and Splices," 1980.
5. American Society for Testing and Materials, "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM A615, 1980.
6. American Society for Testing and Materials, "Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement," ASTM A706, 1980.
7. State of California, Department of Transportation, "Standard Specifications," 1981.
8. State of California, Division of Highways, "Mechanical Properties and Specifications for Welded Joints on Large High Strength Steel Reinforcing Bars," M&R 636328, 1968.
9. State of California, Division of Highways, "Physical Testing of Mechanically Spliced Reinforcing Bar Using a Sleeve with Metal Filler Process," M&R 636328-1, 1967.

10. Robert J. Kudder and David P. Gustafson, "Bend Tests of Grade 60 Reinforcing Bars," ACI Journal, Title No. 80-20.

11. Erasmus, L. A., "Cold Straightening of Partially Embedded Reinforcing Bars — A Different View," Concrete International/June 1981.

**APPENDIX A**

**Recommendations**



# BEND AND STRAIGHTEN GUIDELINES

Bar Size	Carbon Equivalent	Bend Temp. °F	Straighten Temp. °F	Bar Size	Former Dia. Inches Min.
4 through 7	Unknown	1400-1500 <sup>1</sup>	1400-1500	4	3
				5	4
	0.55 or less and A706	70-100 <sup>2</sup> or 1400-1500	70-100 or 1400-1500	6	5
				7	6
8	Any	1400-1500	1400-1500	8	8
>8	BENDING AND STRAIGHTENING NOT RECOMMENDED				

1. Use temperature sticks.
2. Avoid
  - a. 450-600°F
  - b. 1800°F and greater

Note: A. Apply heat to sufficient area to encompass bend area.  
 B. Apply heat for sufficient time to bring bar center to required temperature.  
 C. Maintain temperature while bending - straightening.  
 D. Former should turn freely.  
 E. Bending should be done with smooth continuous application of force.  
 F. Straighten by moving hickey bar (if used) progressively around bend.

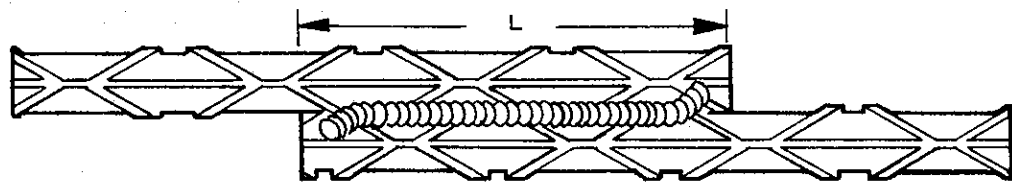
TABLE A

## SPLICE GUIDELINES

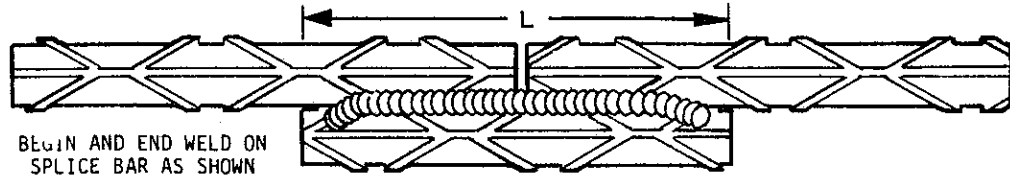
(See figure 2 for splice details)	Process <sup>7</sup>	Electrode <sup>7</sup>	Bar Size
Single lap splice <sup>1,5,6</sup> Detail 1, Types 1a,1b,2a,2b	SMAW FCAW	E9018 GR. E90T	8 and smaller
Double lap splice Detail 2a,2b <sup>2,5,6</sup>	SMAW FCAW	E9018 GR. E90T	8 and smaller
100% penetration butt weld Detail 3a,3b <sup>3,5,6</sup>	SMAW FCAW	E9018 GR. E90T	Any size 8
75% penetration butt weld with flare V groove lap splice - Detail 4 <sup>5,6</sup>	SMAW FCAW	E9018 GR. E90T	8 and smaller
Gr.40 to Gr.60 <sup>5,6</sup>	SMAW FCAW 1,4,5,6,8	E7018 GR.E70T-X	Any size with applicable notes for splice type.
Threaded sleeve coupler			Any size <sup>4</sup>
Filler metal sleeve coupler			Any size <sup>4,9</sup>
Swaged sleeve coupler			Any size <sup>4,9</sup>

1. This detail not recommended for concrete coverage of less than 3 inches.
2. Welding both sides is unnecessary.
3. When backup is not used, root should be backgouged before welding second side.
4. Manufacturer's recommendations should be followed.
5. Welder should have papers documenting his experience at welding rebar or be tested.
6. Preheat weld splices to 600°F and cool slowly (wrap with insulation) to 200°F.
7. SMAW and 1/8" electrode are preferred.
8. Smaller sizes are more difficult to butt weld.
9. Larger sizes (10 and larger) have more difficulty in meeting requirements.

TABLE B



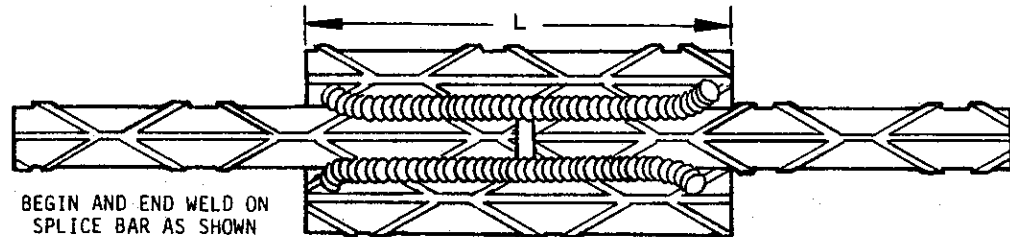
**Type 1**



**Type 2  
Detail 1**

SINGLE LAP SPLICE  
WITH FLARE V GROOVE WELD

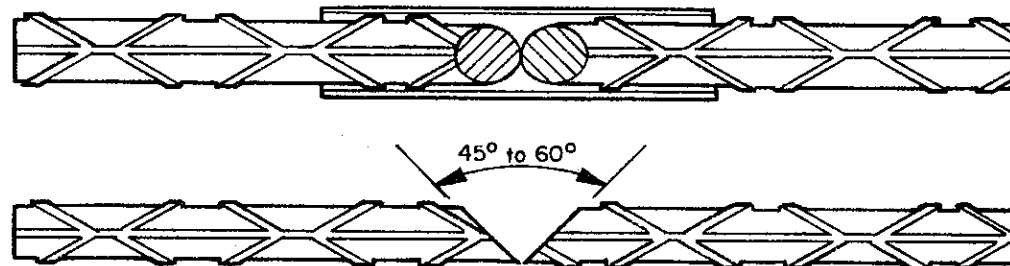
- a. WELD ONE SIDE
- b. WELD BOTH SIDES



**Detail 2**

DOUBLE LAP SPLICE  
WITH FLARE V GROOVE WELD

- a. WELD ONE SIDE
- b. WELD BOTH SIDES

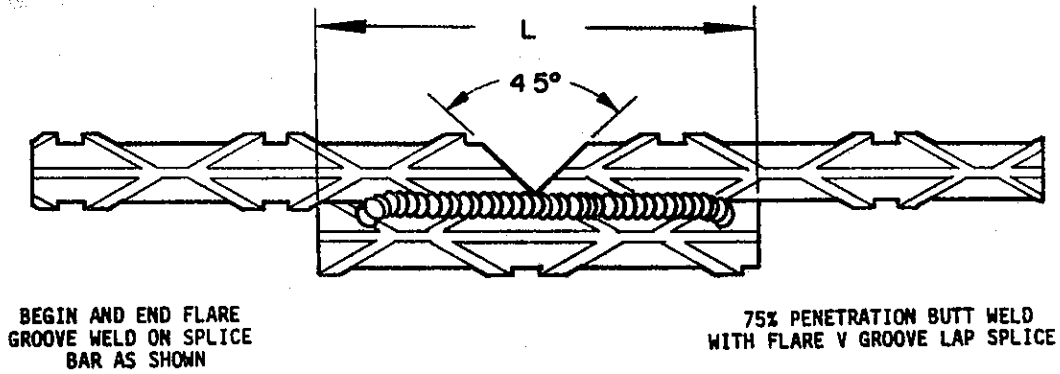


**Detail 3**

100% PENETRATION BUTT WELD

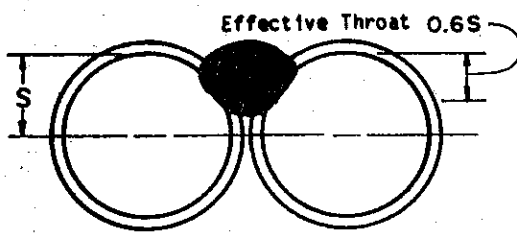
- a. WITH SPLIT PIPE BACKING
- b. NO BACK UP

Figure 2



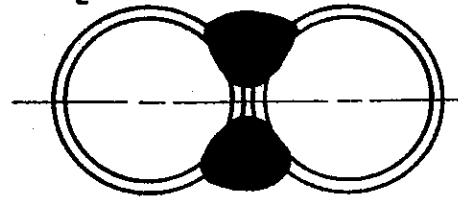
## Detail 4

A.W.S. Value For Flare V Groove Welds



1. FLARE V GROOVE  
WELDED ONE SIDE

$$S = \frac{1}{2} \times \text{Nominal Diameter}$$



2. FLARE V GROOVE  
WELDED BOTH SIDES

Dimensions for Weld Details			
Bar Size	$\ell^*$	$\ell'$	L
#4	1.31	3	4
#5	1.64	4	5
#6	1.96	5	6
#7	2.29	6	7
#8	2.62	7	8

$\ell$  = Minimum calculated weld length (inches) for bars welded on one side.

$\ell'$  = Recommended weld length (inches) for all cases.

L = Recommended lap or splice length (inches).

\* Double  $\ell$  values for Detail 1 type 2.

Figure 2